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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project	Date	Author

SUBJECT—

TITLE

SAMPLING METHODS I. FOREST INSECT LOSS SURVEYS

I. NORTHEASTERN CALIFORNIA

By
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Berkeley, California
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SAMPLING METHODS IN FOREST INSECT LOSS SURVEYS IN NORTHEASTERN CALIFORNIA

INTRODUCTION

In a program of forest protection against insects it is necessary to make an annual survey of timber losses to determine the amount, intensity, and trend and species of insects involved in these infestations causing such losses, to serve as a basis for recommendations for control measures. In the forests of the west coast the most serious insect problems arise as the result of bark beetle infestations. In northeastern California alone during the past 15 years, these insects have killed over 11½ billion board feet of merchantable timber. This represents a drain on the forest resources of this region approximately 1 billion board feet greater than that from lumbering during the same period.

THE PROBLEM

One of the service requirements of the Berkeley Forest Insect Laboratory is an annual estimate of timber losses on about 7 million acres of timber land in the state of California alone. Our main problem is: how best can we arrive at an estimate of losses which will be sufficiently accurate to fulfill the requirements on which control recommendations can be made. There are a number of variable factors which are involved in this main problem. Some of the more important of these include: variations in topography from more or less extensive level plateaus to very steep precipitous ridges, variation in elevations from about 700 feet to over 8,000 feet, variations in the composition of the forest itself from pure stands of one species to mixtures of as many as five or six species, variations in age from very young to overmature, commonly associated in the same area, variation in insect species with some insects specific to certain tree species and others attacking a number of species, often with several species of insects attacking a single tree, and variation in the intensity of the infestation from year to year ranging from 50 board feet per acre to over 500 board feet per acre, and variation in the volume of individual trees attacked from 50 to over 10,000 board feet.

METHODS OF ESTIMATING TIMBER LOSSES IN FORMER USE

Present methods of arriving at an estimate of annual timber losses include both intensive and extensive surveys.

Extensive Methods

Extensive surveys make use of the following methods: Topographic, airplane, strip counts, and general observations. In all these methods it is impossible to assign a sampling error and the reliability of the estimate depends largely upon the experience and care of the man making the observations. Oftentimes there will be a serious discrepancy in the estimate of two equally experienced observers who cover the same region with this type of survey.

General Observations: General observations and impressions are subject to considerable error unless made by a careful experienced observer, and even then the estimates of two equally experienced men may vary considerably for the same area.

Topographic Surveys: Topographic spotting is often used in rough topography where it is possible to see large blocks of timber from certain vantage points. Counts of infested trees are made from such points giving an approximate estimate of infestation conditions. It is difficult to translate these data to an area basis other than in a very rough way, such as so many infested trees to a basin or hillside. DeLeon carried on a study of this type of spotting in 1934 and concluded that it was possible to pick up only about 1/3 of the infested trees in an area with this method.

Strip Surveys: Strip surveys on foot or by car, in which the number of infested trees are counted for a certain distance on each side of the strip has also been used, but again yields results which are only roughly approximate.

Airplane Spotting: Little work has been done in the west with airplane spotting, but it is expected that this method, using a slow, easily maneuverable plane, would serve a very useful purpose in supplying supplemental information on infestation conditions. In 1925 Miller carried on some tests of spotting infested trees from airplane photographs on the Sierra National Forest. He experienced considerable difficulty in always differentiating between infested and green trees. These photos were taken at about 5,000 feet above the terrain and it is likely that pictures taken at a lower elevation would make the differentiation much easier. Craighead and Milford used an autogiro to spot trees infested by the southern pine beetle in Virginia in 1936 and were very enthusiastic about the results obtained. This is one field that should be explored further in the near future.

All the above extensive methods are subject to considerable error in differentiating between trees currently killed and those which were infested the previous year, because of the fact that all trees do not fade at the same rate and the needle retention often differs considerably. Also by these methods no information is obtained on the species of insects involved or their intensity of attack and no figures are available as to the volume of timber destroyed as all estimates are based upon the number of trees.

Intensive Methods

In the intensive type of survey permanent or semipermanent sample plots are used. These are mainly 320 acres in size and are cruised annually, usually late in the fall. A crew of three men are able to cover one plot a day and are able to examine, measure, mark, locate on a map and take information on each infested tree found. This information is necessary in order to determine the species of insects involved in the kill and the volume of timber lost so as to form a basis for control recommendations. A series of 43 of these 320 acre plots have been established in northeastern California in the commercial pine timber type where the bulk of the timber losses have occurred in the past. These are located by National Forests as follows: 17 in the Modoc; 15 in the Lassen; 6 in the Shasta; and 5 in the Plumas. Of the 43 original plots only 23 now remain, the others having been cut in logging operations. About ½ of the plots have been established for 20 years and the balance for over 10 years. The present plot coverage represents about 3/10 of one percent of the total timbered area in these four national forests.

THE PRESENT STUDY OF SAMPLING PROCEDURE

A study of this problem was initiated in 1938 principally to determine what replacements were necessary for the serious depletion of the original number of sample plots. At the same time it seemed wise to study plot size efficiency and to investigate any new methods of spotting or surveying which might be expected to have promise.

Procedure

The manner in which the Berkeley Laboratory has recorded the past losses on the permanent sample plots furnishes an ideal basis for this study. The principal size of permanent sample plots used has been 320 acre units. A detailed map for each plot has been made showing physical features and broad timber types. These maps have been divided into 5 x 5 chain square units containing 2.5 acres each, and each tree killed has been spotted on this map to the nearest 2.5 acres. This has made possible the combining of these smaller units unto plots of various sizes and shapes. Figure 1 illustrates one of these maps for Modoc Plot R.S. 5 on which the 1933 loss has been spotted. From this, a general picture is possible of the distribution of losses for a single year. Figure 2 illustrates the size and shape of the different size units used in this sampling study. These were 5, 10, 20, 40, 80, and 160 acre units respectively. The original data on which this study was based, included all permanent sample plots in the Modoc, Lassen, and Shasta National Forests on which records were available from 1931 to 1936 inclusive. The average volume b.m. loss per acre was computed for each plot of various size for each year and for a 6 year average. The relative efficiency of each size plot was then determined by measuring the relative variability between plots of different sizes and shapes.

Figure 1

Distribution of insect losses for 1933 on regional survey plot 5 in the Modoc National Forest. The location of each tree killed on this 320 acre plot is indicated thus: •

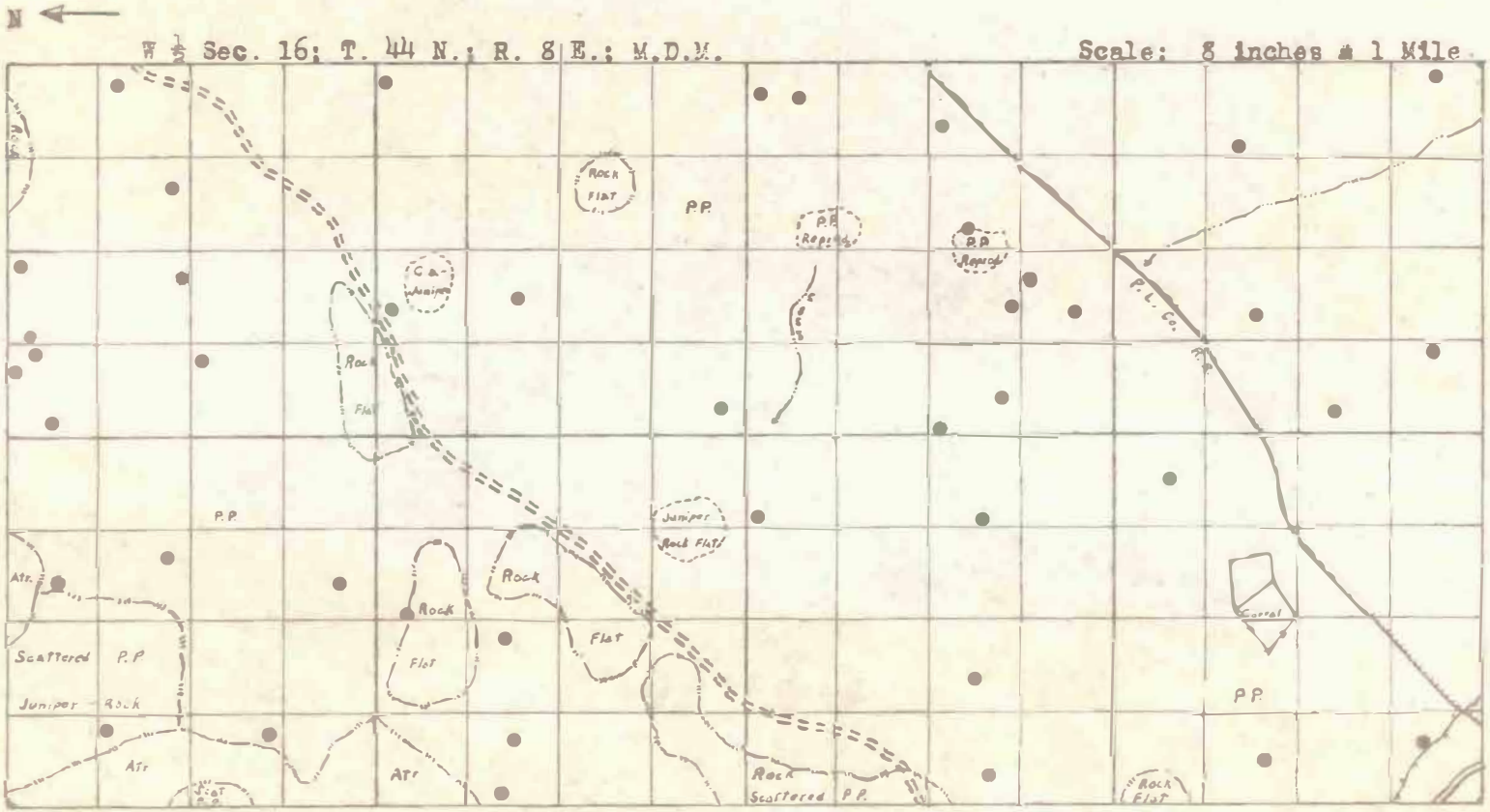


Figure 2.

Size and shape of plots used in this sampling study of barkbeetle losses. The total area represents a 320 acre permanent sample plot. Past losses have been spotted annually on each plot map according to the smallest unit, 2.5 acres, making it possible to build up any size of plot desired.

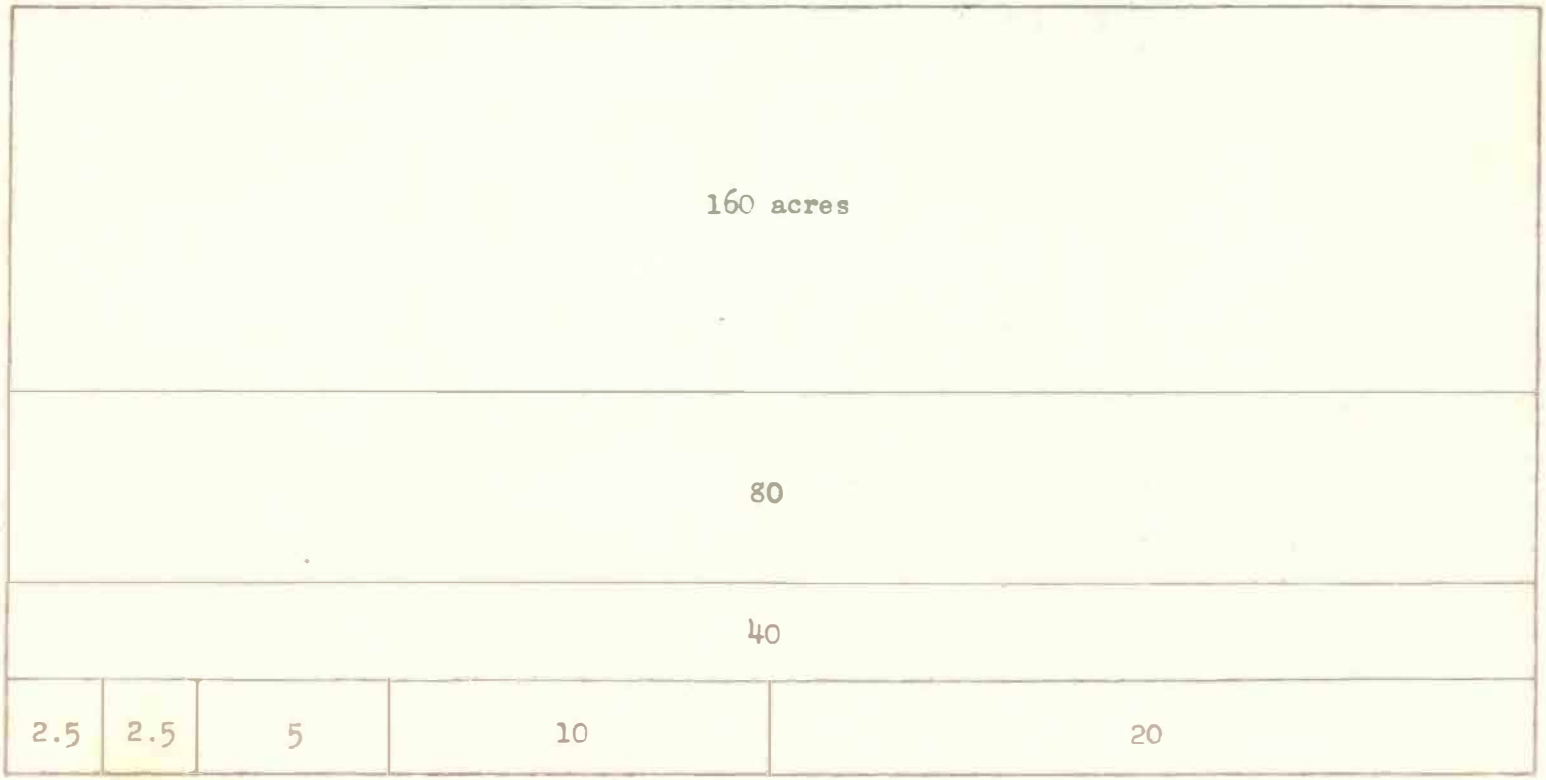


Figure 3

Plot RS-5, Modoc National Forest

Average Volume B.M. Loss per Acre for 1933 by Different Size Plots.

Average Volume B.M. Loss per Acre per Year for the Period 1931-1936 Inclusive by Different Size Plots

41	352
22	3
105	280
168	114
0	85
217	0
152	2
201	288

266	261
286	246
375	267
236	213
209	178
177	124
160	146
114	137

20 Acre Plots

197
12
193
141
43
109
77
245

264
266
321
224
194
150
153
126

40 Acre Plots

104
167
76
161

265
272
172
139

80 Acre Plots

136
118

269
155

160 Acre Plots

Results

Figure 3 illustrates the range in average loss per acre for plots of different sizes for plot R.S. 5 for 1933 and the average per acre per year loss for a 6 year period. Note that the range in loss in the smaller plots is relatively much greater for a single year than it is for the average for 6 years. Note also that there are two 20 acre plots in 1933 on which no loss occurred, but that for the average year all plots registered loss.

The average volume loss per acre for plot R.S. 5 for 1933 was 127 board board feet and the average for the 6 year period was 212 board feet. Note that although there is considerable variation in the 20 acre plots, the combining of these smaller plots into larger units even up to 160 acres has not materially reduced the variation, and it has been found that there would still be considerable variation in 320 acre plots which are side by side.

Plot Efficiency

Theoretically the most efficient plot size of those tested proved to be the 5 acre unit. However, the gain in efficiency of the fives over the tens and the tens over the twenties was so slight that they can hardly be considered practical. The slight gain in magnitude in the efficiency of these smaller plots is attributed to the frequent occurrence of zero observations. A considerable gain in efficiency is obtained, however, in the 20 acre unit over the 40 (Table 1). If the 20 acre unit is considered as representing 100 percent efficiency, then the 40 acre unit is only 83.3 percent as efficient; that is for a given degree of precision it would be necessary to sample only 83.3 as much acreage in 20 acre plots as would be needed using the 40 acre unit. This is similar to the results reported by Pasal in his study of sampling timber. A comparison of the 20 acre units with the 320 acre units shows that only 22.5 percent as much area needs to be covered with the small plots.

Table 1. Efficiency of Sample Plots of Different Sizes Based upon Data of thirty 320 acre Plots for the Year 1931 with an average volume loss of 187 board feet per acre.

Plot Size Acres	Variance of a Basic Plot	Efficiency	Relative Size of Sample for a Given Precision of Estimate
20	51.475	100.0	1.00
40	61.564	83.3	1.20
80	94.096	54.6	1.83
160	140.704	36.6	2.73
320	228.720	22.5	4.44

There appears to be considerable variation in plot efficiency, however, from year to year. For the years tested the relative efficiency of the 320 to the 20 ranged from 12.6 in 1934, a year of high loss, to 25.6 in 1936, a year of low loss. The general trend appeared to show that the smaller plots were relatively more efficient when losses were high than when they were low. The 1931 figures, presented in the above table, appear to represent average conditions for efficiency and loss for the period studied.

Shape of Plot

The shape of a plot appears to have some effect on its efficiency, although only slightly so. It was found that the long narrow plot was generally more efficient than a square one. From Table 2 it may be noted that a square 40 acre plot, 20 x 20 chains, is only about 86 percent efficient as compared to a plot of the same size but whose dimensions are 5 x 80 chains.

Table 2. Relative Efficiency of Plots of Different Shape

Plot Dimensions	Variance of Single Basic Plot	Efficiency	Relative Size of Sample for a Given Precision of Estimate
5 x 80 chains	25,998	100.0	1.00
10 x 40 chains	27,888	93.4	1.07
20 x 20 chains	30,414	85.5	1.17

Sampling Error

It was found that the sampling error percent* was reasonably consistent from year during the period of 1931 to 1936 ranging from 8.4 to 10.8 percent for the 20 acre units although the range in loss for this same period was from 103 to 293 board feet per acre. It was also found that the sampling error percent was fairly consistent, during this period, within each of the three National Forests studied. On the Modoc the range in loss was from 124 to 431 board feet per acre with a sampling error of from 12.2 to 18.0 percent. On the Lassen the range in loss was 108 to 242 board feet per acre with a sampling error range from 11.4 to 15.8 percent. Losses on the Shasta were considerably more variable than on the other two forests. Losses were lighter, ranging from 44 to 148 board feet per acre while the range in sampling error was from 21.9 to 37.2 percent. In general it appeared that the sampling error percent decreased with an increase in the magnitude of the loss.

Practical Application of Results

After the preliminary analysis of the above plot data, it was decided to submit the results to a practical test, using the 20 acre unit as a base. In 1939 a series of 40 of these small plots were established in

* Sampling error percent is expressed here as two standard errors divided by the mean.

Shasta County in the Burney Unit. These were assigned in essentially a random manner. Data were collected on the time necessary to establish these small units, and also the time necessary to cruise them. Loss data have been accumulated for a four year period on these plots. It is interesting to observe the actual performance of these plots compared to their expected performance. There are only 37 plots on which we have complete four year records and the analysis is based upon that number. The data from the Shasta National Forest were taken as a base from which to calculate the expected performance of these plots. We might logically expect that 37 plots would yield a sampling error ranging from 34 to 54 percent based upon the performance of the Shasta plots for the 6 years previously studied. The actual performance is shown in Table 3, where it may be noted that the sampling error for the past four years falls well within the expected limit. The actual sampling error for the four years ranged from 35 to 48 percent.

Table 3. Results of the use of 37, 20-acre Sample Plots to Sample Losses in the Burney Unit.

Year	1938	1939	1940	1941
Average Annual Loss, b.m. per acre	82	122	176	83
Standard Deviation	87	130	189	122
Standard Error	15	21	31	20
Sampling Error Percent	38	35	36	48

The question now arises as to whether the results obtained are accurate enough for the purposes of recommending control work. A sampling error of about 40 percent for the whole unit of about 250,000 acres seems very high and may not be much better than a guess on the part of an experienced observer. While we have some interest in the picture for the whole unit so far as total depletion figures are concerned, we are more interested in the picture on small units where control would actually be applied and on these small units the small plots are far from adequate. Therefore this study was broadened to attempt to find a substitute for formal plots which would yield a greater coverage of area for the labor expended.

The system finally adopted as the most satisfactory of any attempted was the use of road strips, ten chains in width and 80 chains in length, containing 80 acres. These are cruised from the back end of a pickup truck fitted up with a seat. These were tested in a preliminary way during the 1940 field season in the Burney area and at Black's Mountain Experimental Forest. In the test at Black's Mountain a sample of approximately 25 percent was covered by these strips. In this first attempt the size of each infested tree was estimated and spotted on a map. This estimate was then compared with the data which Bongberg's crew had obtained in their 100 percent coverage of the area. Table 4 offers a comparison of these data. It may be noted from this table that the estimated volume loss for 1939 was 112 board feet ±13 compared to the true volume of 102 board feet. The average diameter of each infested tree was estimated

at 34" while the true average diameter was 32". These estimated figures were obtained at an expenditure of 3 man days compared to about 75 man days for the 100 percent sample obtained by the standard three man crew. The results of this preliminary test were encouraging enough so that this system was given a further test in the Burney area. In 1940 this method was improved so that the same data would be collected on the strips as that obtained on plot surveys. Each infested tree was examined, blazed, marked, measured and spotted on a map and data collected on the insect species involved in the kill.

Table 4. Results of a Road Strip Survey of Black's Mountain Experimental Area compared with a 100 percent Cruise by Standard Methods, 1939 Loss.

	Road Strip	100 Percent Cruise
Number miles cruised	35	114
Timbered acres cruised	2,488	9,100
Percent of area cruised	27	100
Average loss per acre	112 bd.ft.	102 bd.ft.
Standard error	13%	--
Average diameter	34"	32"
Cruising time (in man days)	3	75
Estimated cost	$18	$450

It was decided to set up this system so as to allow for a sampling error of 15 percent. The expected acreage in 80 acre units was about 8,500 acres. Ninety-one of these units were established in 1940 and the data for that year have been analyzed. The average loss from these units was 127 board feet per acre, with a standard error of 8 board feet and a sampling error of 13 percent. This agrees reasonably well with the expected sampling error of 15 percent.

Efficiency of the Different Systems

Table 5 presents data on the number of acres which it is possible to cruise each man day with the various systems. Here the yield from cruising time is about the same for the plots but a considerable gain is possible in the road strips. It is possible with the latter to cruise about 5 times the acreage per man day we could be accomplished with either plot system. Table 5 presents data on the number of acres needed with the various systems which will yield a sampling error of 15 percent. Note that although almost double the acreage is needed in the 80 acre plots over that necessary in the 20 acre plots, it is possible to cruise the former in much less than half the time needed for the latter. The 320 acre plots would take about 13 times as long to cruise as the 80 acre units for the same degree of accuracy. The road strip has an additional advantage over the other systems in that no time is required to establish plot boundaries. The 20 and 320 acre units would require a minimum of 500 man days for plot location and establishment

alone. The road strip system appears well adapted to country which is well traversed with roads and where the topography is reasonably level. In extremely steep topography or where road systems are not adequate some modification will be necessary.

Table 5. Efficiency of Different Systems of Surveying Timber Losses with an Allowable Sampling Error of 15 Percent

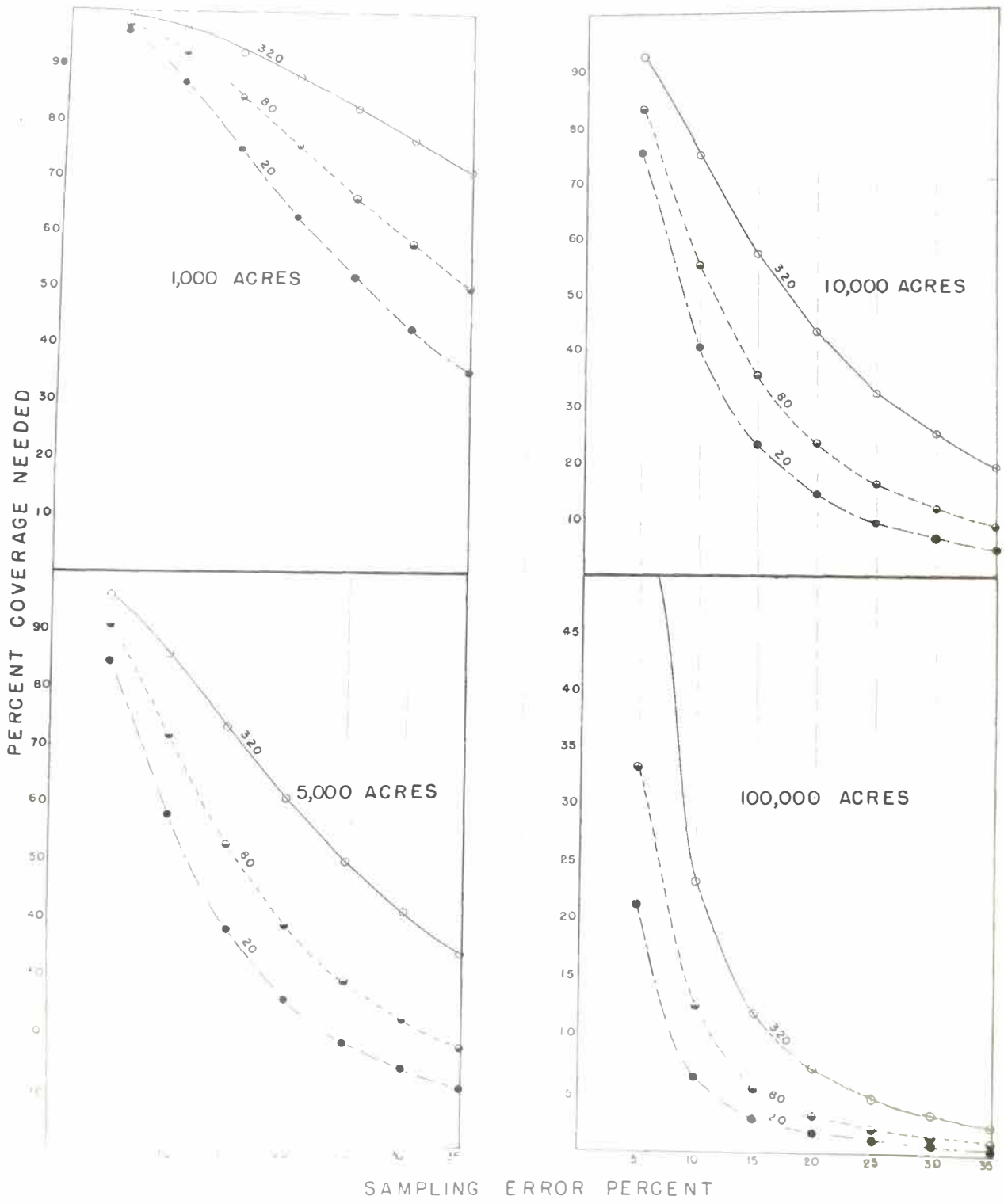
Plot System	No. Acres Needed	No. Plots Needed	No. Acres Cruised per Man Day	No. Man Days Needed to Cruise	Efficiency
20	3,920	196	120	33	36.4
80	7,210	90	680	12	100.0
320	17,336	54	107	162	7.4

Intensity of Coverage

One of the basic principles of sampling is that as the size of the area to be sampled decreases the intensity of coverage needed increases. This point is of very practical interest in sampling timber losses caused by insects. For example, a 3 percent coverage of 100,000 acres would yield the same precision of estimate as a 75 percent coverage of 1,000 acres. It is particularly important in control recommendations on small tracts that this principle be appreciated when furnishing estimates of the number of trees to be treated. In areas under a thousand acres it usually will be necessary to make a 100 percent cruise to obtain a valid estimate. Table 6 and figure 4 furnish data on the intensity of coverage needed, for areas of different sizes, by different plot systems, for a given precision of estimate. The sampling error percent as used here is based on two standard errors divided by the average loss. If for example we had a problem of sampling loss on 100,000 acres of timberland by 20 acre plots and would be satisfied with a sampling error of 10 percent, we would expect that a 6 percent coverage of the area would yield an estimate of loss for this area which 19 times out of 20 would fall within the limits of a 10 percent sampling error.

Table 6. Percent of Sample Coverage Necessary in Areas of Various Sizes, by Use of Different Plot Systems.

Plot Size Acres	Area to be Sampled - Size in Acres			
	1,000	5,000	10,000	100,000
	Sampling Error - 5%			
20	96.4	84.5	75.3	21.4
80	97.6	90.8	83.4	33.3
320	99.2	96.0	92.5	54.8
	Sampling Error - 10%			
20	87.2	57.8	40.6	6.4
80	92.8	71.4	55.5	12.5
320	97.0	85.8	75.2	23.3
	Sampling Error - 15%			
20	75.2	37.8	23.3	2.9
80	84.8	52.6	35.7	5.3
320	92.8	73.1	57.6	11.9
	Sampling Error - 20%			
20	63.0	25.4	14.6	1.7
80	76.0	38.4	23.8	3.0
320	86.3	60.3	43.2	7.1
	Sampling Error - 25%			
20	52.2	17.9	9.9	1.1
80	66.4	28.5	16.6	2.0
320	82.9	49.3	32.6	4.6
	Sampling Error - 30%			
20	43.2	13.2	7.1	0.8
80	58.4	21.8	12.2	1.4
320	77.1	40.3	25.3	3.3
	Sampling Error - 35%			
20	35.8	10.0	5.3	0.5
80	50.4	17.0	9.3	1.0
320	71.4	33.2	19.8	2.4


1,000 ACRES
10,000 ACRES
5,000 ACRES
100,000 ACRES
320
80
20
PERCENT COVERAGE NEEDED
SAMPLING ERROR PERCENT

Recommendations for Future Study

Our present survey coverage using large sample plots of 320 acres appears to be definitely inadequate for most of the areas where we must annually make an estimate of timber losses. This is particularly true since we have lost almost 50 percent of the original number which were established. The sampling error for each Forest covered with these limited large plots ranges from about 25 to 50 percent annually, and yet we are expending a tremendous amount of man power each year to get these rather unreliable estimates. This study indicates for example that we are expending about $13 in getting information from the 320 acre plots where only $1 would be needed in road strips. To express it another way, if we put our present survey resources into a series of road strips, wherever the topography of the country would permit, with the same expenditure of time we could reduce our average sampling error from about 35 percent down to around 8 percent for each year.

Further studies are needed on this problem in the near future. Particularly pressing is the need for further checking the road strips to make sure that they are free of bias. It must be determined, for example, whether conditions along road systems differ in any way from conditions generally throughout the stand. This can be determined rather simply by further analysis of existing sample plot data on those plots which contain roads, by a comparison of losses along roads with losses in the rest of the plot. This could further be checked in areas where plots do not now exist by comparing losses on road strips with a strip cruise of equal width back into the stand where road effects would be at a minimum. Cruise data from the Black's Mountain Experimental area could also be used for this purpose.

Further work should also be done on the most practical system of sampling loss in mountainous topography where present road systems are inadequate. In general, however, the road strip system appears well adapted to the bulk of the timbered area embracing the commercial Eastside timber type.

The possibility of the use of airplane spotting should be investigated further in the near future.

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APPENDIX

Formula (1)

The mean or average volume loss per acre, represented by $\bar{x}$

$$\bar{x} = \frac{\Sigma x}{N}$$

in which

x = average loss per acre on each plot
Σx = total loss per acre on all plots
N = number of plots

Formula (2)

Variance represented by V

$$V = \frac{\Sigma (x)^2 - \frac{(\Sigma x)^2}{N}}{N - 1}$$

in which

$\Sigma (x)^2$ = sum of squares of loss per acre on each plot
$\Sigma (x)^2$ = sum of loss per acre on all plots squared
N = number of plots

Formula (3)

Standard deviation, represented by σ

$$\sigma = \sqrt{V}$$

Formula (4)

Standard error, represented by SE

$$SE = \frac{\sigma}{\sqrt{N}}$$

Formula (5)

$$SE \text{ for finite sampling} = \frac{\sigma}{\sqrt{N}} \sqrt{1 - \frac{n}{N}}$$

in which n = sample number
N = total number of samples possible in the finite sample.

Formula (6)

Sampling error in percent, represented by SME

$$SME = \frac{(SE)\ (2)}{\bar{x}}$$

Formula (7)

For a given degree of precision to determine the number of plots needed for finite sampling.

$$n = \frac{N \cdot V}{N \cdot V_{\bar{x}} + V}$$

in which

n = number of plots needed
N = number of plots of the size selected which would be possible to put into the size of the area to be sampled.
Example: For 20 acre plots in a sampling area of 10,000 acres, $N = \frac{10,000}{20} = 500$

V = expected variance of the plot size selected. This must be obtained from studies of the variation of plots of this size under conditions similar to that in the proposed area.

$$V_{\bar{x}} = \left[(\bar{x})\ \left(\frac{SME}{2}\right)\right]^2$$

in which

$\bar{x}$ = average loss per acre in a sample coverage from the same area or a similar area.
SME = sampling error percent which will be accepted.

Example:

To find the number of 20 acre plots needed to sample 10,000 acres to yield a 10% sampling error.

$\bar{x}$ = 245 board feet per acre
V = 51,475
SME = 10%
N = 10,000/20 = 500

$$n = \frac{500 \cdot 51,475}{500 \cdot \left[245 \cdot \frac{10\%}{2}\right]^2 + 51,475}$$

= 203 plots

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